UNIVERSITY OF SASKATCHEWAN
Department of Civil Engineering

CE 212.3 – Civil Engineering Materials

FINAL EXAMINATION
December 18, 2004

Time Allowed: 3 hours Professor: L. D. Wegner

Student Name:____**Number:**________________

Notes:
- Closed book examination.
- Calculators permitted.
- The value of each question is provided along the left margin.
- **Supplemental material is appended to the end of the examination paper**.
- Answer all questions in the space provided. If you need more room, use the back of the page, and indicate in the space provided where the solution may be found.
- Exam consists of 13 pages and 21 questions for a total of 100 marks.

Marks

4 **1.** What are the advantages and disadvantages of fracture mechanics based toughness testing as compared with impact toughness tests such as the Charpy test?

2 **2.** What is a composite material and why would one choose to use a composite material instead of a material from one of the other categories of solids?

3 **3.** List three possible changes that could take place in the heat affected zone due to welding of a steel, emphasizing their effect on mechanical properties.

3 **4.** True or false: Given an equilibrium phase diagram, it is always possible determine with certainty the phases present, phase compositions, and phase amounts for a given combination of temperature and overall composition of a material system. Explain your answer.

4 **5.** What are the mechanisms (at the atomic scale) by which plastic deformation takes place in metals and thermoplastic polymers?

2 **6.** Explain why glass fibres produced for use in a fibre-reinforced composite material can possess a tensile strength that is much greater than that of the glass used in for a window pane.

5 **7.** Explain why materials expand when heated. Use a diagram if possible.

4 **8.** Why is gypsum added to Portland cement? Describe how the gypsum performs its intended function.

4 **9.** Creep and shrinkage of Portland cement concrete both result from the movement of water within the microstructure. Explain two similarities and two differences between the mechanisms by which each takes place.

3 **10.** Explain the purpose of an air entraining admixture for concrete. Under what conditions would this type of admixture be used?

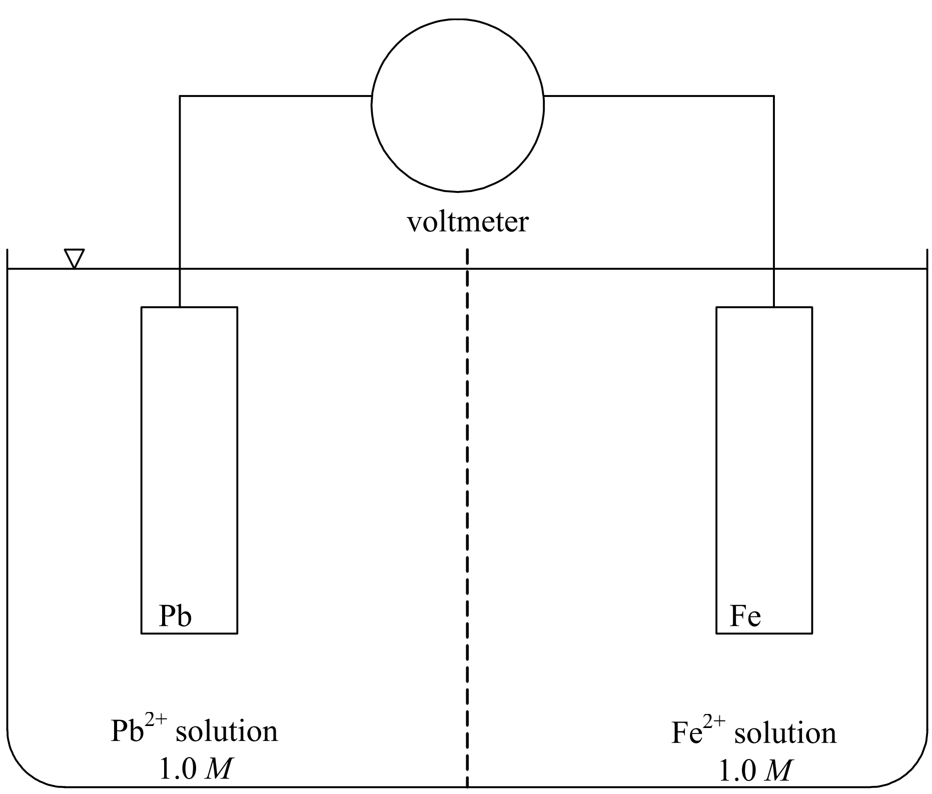
2 **11.** What is the difference between melting temperature and glass transition temperature for a thermoplastic polymer?

3 **12.** List at least three methods for controlling the corrosion of reinforcing steel in reinforced concrete.

6 **13.** A batch of Portland cement concrete is mixed with a water/cement ratio of 0.45. Assuming that the hydration reactions proceed to 85% completion, estimate

(a) The capillary porosity in the cement paste;
(b) The strength of the cement paste; and
(c) The elastic modulus of the concrete (assuming that the concrete has a similar strength to the cement paste).

8 **14.** Label the lead-iron galvanic couple diagram given below to show the following information: anode, cathode, direction of electron flow, movement of metal ions, voltmeter reading, and locations of corrosion and electro-plating. Write out the oxidation and reduction half-cell reactions.



Half-cell reaction:

Half-cell reaction:

5 **15.** For a certain iron-carbon alloy, the mass fractions of total ferrite and total cementite are 0.75 and 0.25, respectively.

(a) On the basis of carbon content, would this alloy be classified as a steel or a cast iron? Why?

(b) What is the mass fraction of pearlite in this system?

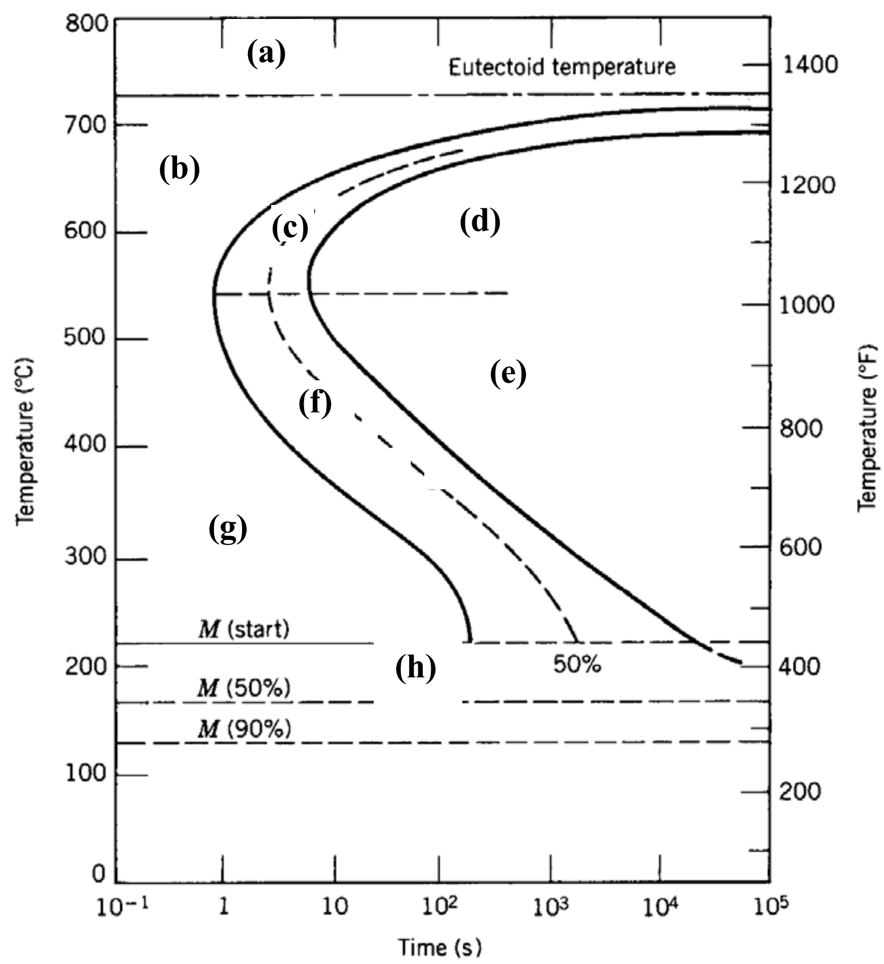
6 **16.** A fibre reinforced polymer (FRP) composite consists of unidirectional, continuous E-glass fibres with a volume fraction of 57% embedded in an epoxy matrix. Using the information appended at the end of this exam, estimate

(a) the density of the FRP;

(b) the Young's modulus of the FRP when pulled in the direction of the fibres; and

(c) the Young's modulus of the FRP when pulled in a direction perpendicular to the fibres.

5 **17.** Given the isothermal transformation diagram for a eutectoid steel below, label the phases that appear in the regions marked (a) through (h), and suggest an isothermal heat treatment that will produce 50% of the phase in region (e) and 50% of the phase in region (h). Sketch the heat treatment on the diagram



(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

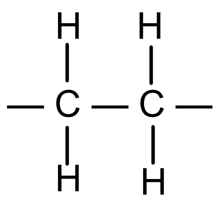
Heat treatment:

9 **18.** Below are given the molecular weight data for a high density polyethylene (HDPE) polymer.

(a) Calculate the number average degree of polymerization.

(b) A plastic cup made from this particular polymer has a mass of 70 g. How many polymer chains are contained in this cup?

(c) Calculate the weight fractions that are missing in the table.



Polyethylene mer unit

Molecular Weight Range (g/mol)	w_i	x_i
15,000 – 25,000	0.016	0.04
25,000 – 35,000	0.064	0.11
35,000 – 45,000	0.140	0.18
45,000 – 55,000	w_4	0.27
55,000 – 65,000	w_5	0.20
65,000 – 75,000	0.205	0.15
75,000 – 85,000	w_7	0.05

8 **19.** The Maxwell model (spring and dashpot in series) for viscoelastic behaviour results in the following stress-time (σ-t) relationship:

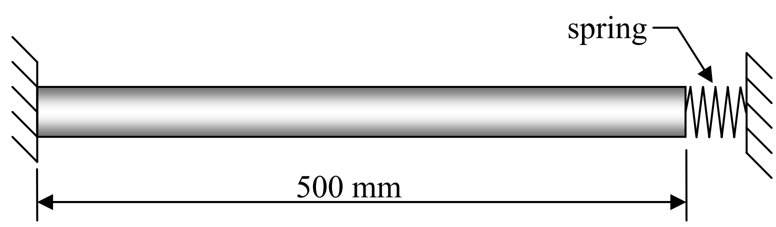
$$\sigma = \sigma_o e^{\frac{-E}{\mu}t}$$

where E is the elastic modulus, μ is the viscosity, σ_o is the initial stress, and t is the time in seconds. A certain viscoelastic polymer with an elastic modulus of 700 MPa and viscosity of 9×10^{11} Pa·s is suddenly pulled in tension to a strain of 0.10. Determine the relaxation modulus at 100 seconds, assuming that the stress relaxes according to the Maxwell model equation given above.

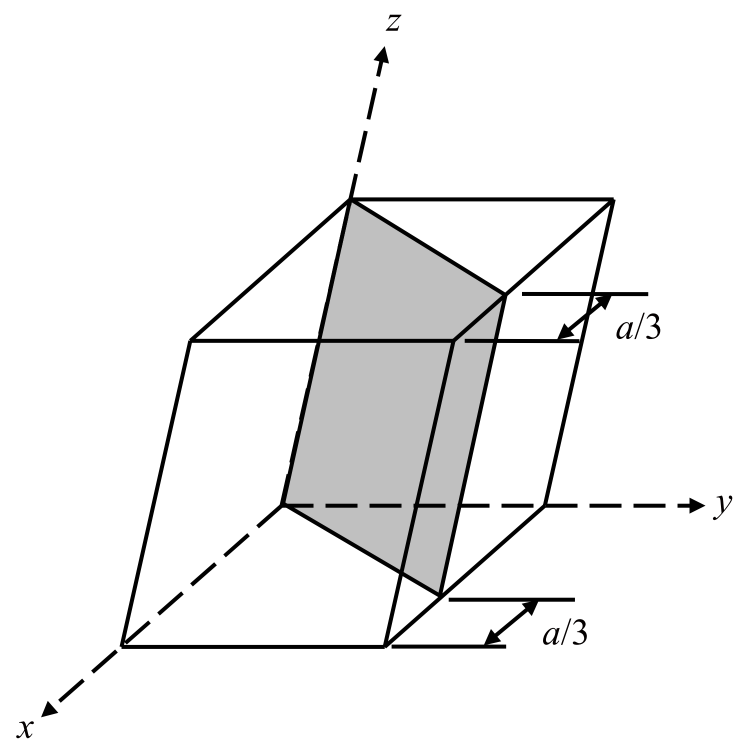
8 **20.** A rod of aluminum, 500 mm long and 50.000 mm in diameter, is heated from 20°C to 150°C. Two different restraint conditions are considered for the following questions.

(a) First consider the rod to be completely free to expand or contract without restraint. Calculate the change in length that results when it is heated.

(b) For the second restraint condition, one end of the rod is fixed against movement, while the other is attached to a spring with a stiffness of 100 kN/mm, as shown. Calculate the force that develops in the rod when it is heated, assuming that there is no force before heating. Be sure to identify it as being tension or compression. (hint: the force in the spring must equal the force in the rod.)



6 **21.** Calculate the Miller indices for the plane shown.



---THE END---

EQUATIONS:

$$\text{APF} = \frac{\text{volume of atoms in a unit cell}}{\text{total unit cell volume}} \qquad \rho = \frac{nA}{V_c N_A}$$

$N_A = 6.023 \text{ x } 10^{23}$ $\qquad k = 1.38 \text{ x } 10^{-23}$ J/atom-K $\qquad R = 8.31$ J/mol-K

Arrhenius Equation: $\text{Rate} = Ce^{-Q/RT}$ or $\text{Rate} = Ce^{-q/kT}$ $\qquad N_v = Ne^{-Q_v/RT}$

$$C_1 = \frac{m_1}{m_1 + m_2} \text{ x } 100 \qquad C_1' = \frac{n_{m1}}{n_{m1} + n_{m2}} \text{ x } 100 \qquad C_1' = \frac{C_1 A_2}{C_1 A_2 + C_2 A_1} \text{ x } 100$$

$$C_1 = \frac{C_1' A_1}{C_1' A_1 + C_2' A_2} \text{ x } 100 \qquad W_L = \frac{C_\alpha - C_o}{C_\alpha - C_L} \qquad V_\alpha = \frac{\frac{W_\alpha}{\rho_\alpha}}{\frac{W_\alpha}{\rho_\alpha} + \frac{W_\beta}{\rho_\beta}} \qquad \sigma_x = E\varepsilon_x$$

$$W_\alpha = \frac{V_\alpha \rho_\alpha}{V_\alpha \rho_\alpha + V_\beta \rho_\beta} \qquad J = -D\frac{dc}{dx} \qquad D = D_o e^{-Q/RT} \qquad \sigma = F/A$$

$$\nu = -\frac{\varepsilon_{lateral}}{\varepsilon_{longitudinal}} \qquad \tau_{xy} = G\gamma_{xy} \qquad p = -K\Delta \qquad G = \frac{E}{2(1+\nu)}$$

$$U_r \approx \frac{1}{2}\sigma_Y \varepsilon_Y \qquad \%\text{EL} = \left(\frac{l_f - l_o}{l_o}\right) \times 100 \qquad \%\text{AR} = \left(\frac{A_o - A_f}{A_o}\right) \times 100$$

$$\varepsilon_T = \ln\frac{l}{l_o} \qquad \sigma_T = \sigma(1+\varepsilon) \qquad \varepsilon_T = \ln(1+\varepsilon)$$

$$\tau_r = \sigma\cos\phi\cos\lambda \qquad \eta = \frac{\tau}{dv/dy} \qquad \dot{\varepsilon} = \frac{\sigma}{\mu} \qquad \dot{\gamma} = \frac{\tau}{\eta}$$

$$\dot{\varepsilon}_{ss} = A\sigma^n e^{-Q/RT} \qquad E_c(t) = \frac{\sigma_o}{\varepsilon(t)} \qquad E_r(t) = \frac{\sigma(t)}{\varepsilon_o}$$

$$K_t = \frac{\sigma_m}{\sigma_o} \qquad K_t = \left[1 + 2\left(\frac{a}{\rho_t}\right)^{1/2}\right] \qquad G = \frac{\pi\sigma^2 a}{E}$$

$$K = Y\sigma\sqrt{\pi a} \qquad \sigma_c = \frac{K_{Ic}}{Y\sqrt{\pi a}} \qquad a_c = \frac{1}{\pi}\left(\frac{K_{Ic}}{\sigma Y}\right)^2$$

$$K = \sqrt{GE} \qquad P_s(V_o) = e^{\left[-\left(\frac{\sigma}{\sigma_o}\right)^m\right]} \qquad P_s(V) = [P_s(V_o)]^n = [P_s(V_o)]^{V/V_o}$$

$$\frac{\sigma}{\sigma_o} = \left[-\frac{V_o}{V}\ln(P_s(V))\right]^{1/m} \qquad \sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} \qquad \sigma_a = \frac{\sigma_{\max} - \sigma_{\min}}{2}$$

$$\frac{da}{dN} = A(\Delta K)^m \qquad N_f = \frac{1}{A\Delta\sigma^m \pi^{m/2}}\int_{a_o}^{a_c}\frac{da}{Y^m a^{m/2}} \qquad (\Delta m)^2 = k_p t$$

$$k_P = A_P e^{-Q_P/RT} \qquad \Delta m = k_L t \qquad k_L = A_L e^{-Q_L/RT}$$

$$\varepsilon_t = \alpha_l \Delta T \qquad \sigma_t = -E\alpha_l \Delta T \qquad \frac{\Delta V}{V} = \alpha_v \Delta T \qquad y = 1 - e^{-kt^n}$$

$$\sigma_c = 100(1 - P_{cap})^3 \text{ MPa} \qquad P_{cap} = \frac{w/c - 0.36\alpha}{w/c + 0.32} \qquad E = 3300\sqrt{f_c'} + 6900$$

$$\overline{M}_w = \sum w_i M_i \qquad \overline{M}_n = \sum x_i M_i \qquad n_w = \frac{\overline{M}_w}{\overline{m}} \qquad n_n = \frac{\overline{M}_n}{\overline{m}}$$

$$\rho_c = \rho_r V_r + \rho_m V_m \qquad E_{c(upper)} = E_r V_r + E_m V_m \qquad E_{c(lower)} = \frac{E_r E_m}{E_r V_m + E_m V_r}$$

DATA:

(1 g = 6.023×10^{23} amu)

Characteristics of Selected Elements

Element	Symbol	Atomic Weight (amu)	Density at 20°C (g/cm^3)	Crystal Structure	Atomic Radius (nm)
Hydrogen	H	1.008	—	—	—
Carbon	C	12.011	2.25	Hex.	0.071
Iron	Fe	55.85	7.87	BCC	0.124

Properties of Selected Materials

Material	α_l (/°C)	Young's modulus (GPa)	Poisson's ratio	Density (g/cm^3)
E-glass	5.0×10^{-6}	72.5	0.22	2.55
Epoxy	60×10^{-6}	4.0	0.40	1.25
Aluminum	23.6×10^{-6}	69.0	0.33	2.71

α_l = linear coefficient of thermal expansion

Table 18.1 The Standard emf Series

	Electrode Reaction	*Standard Electrode Potential, V^0 (V)*
↑	$Au^{3+} + 3e^- \longrightarrow Au$	+1.420
	$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$	+1.229
	$Pt^{2+} + 2e^- \longrightarrow Pt$	~+1.2
	$Ag^+ + e^- \longrightarrow Ag$	+0.800
Increasingly inert (cathodic)	$Fe^{3+} + e^- \longrightarrow Fe^{2+}$	+0.771
	$O_2 + 2H_2O + 4e^- \longrightarrow 4(OH^-)$	+0.401
	$Cu^{2+} + 2e^- \longrightarrow Cu$	+0.340
	$2H^+ + 2e^- \longrightarrow H_2$	0.000
	$Pb^{2+} + 2e^- \longrightarrow Pb$	−0.126
	$Sn^{2+} + 2e^- \longrightarrow Sn$	−0.136
	$Ni^{2+} + 2e^- \longrightarrow Ni$	−0.250
	$Co^{2+} + 2e^- \longrightarrow Co$	−0.277
	$Cd^{2+} + 2e^- \longrightarrow Cd$	−0.403
	$Fe^{2+} + 2e^- \longrightarrow Fe$	−0.440
Increasingly active (anodic)	$Cr^{3+} + 3e^- \longrightarrow Cr$	−0.744
	$Zn^{2+} + 2e^- \longrightarrow Zn$	−0.763
	$Al^{3+} + 3e^- \longrightarrow Al$	−1.662
	$Mg^{2+} + 2e^- \longrightarrow Mg$	−2.363
	$Na^+ + e^- \longrightarrow Na$	−2.714
↓	$K^+ + e^- \longrightarrow K$	−2.924